



CONCARDIO MEDICAL INSTRUMENTS INC.

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December 20, 2004

Dr. Andrew Rawicz
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Re: ENSC 340 Post-Mortem: The CMI Cardiac Action Potential Imaging System (CAPIS)

Dear Dr. Rawicz:

Attached with this letter is the *Post-Mortem: The CMI Cardiac Action Potential Imaging System*, which was previously described in our project proposal. We are developing an optical mapping tool that will record electrical signals from a small heart for analysis of irregular heart pulses associated with JET arrhythmia.

The purpose of the following document is to describe the current state of system, differences from our original design specifications, and recommendations on future plans with the CAPIS system. Also included in this document are outlines of our time constraints, budget, and the interpersonal and technical experience gained by each individual through working on this project.

The Engineering 340 project team at Concardio Medical Instruments Inc., consists of Ronnie Chan (CEO), Yindar Chuo, Jimmy Tsui, Edwin Wong, and Stephen Wong. Please contact us if there are any questions or concerns via email, ensc-bcri@sfu.ca or by phone through Ronnie Chan at 778-891-3837. Thank you.

Sincerely,

Ronnie Chan

Ronnie Chan
Chief Executive Officer
Concardio Medical Instruments Inc.

Enclosure: *Post-Mortem for the CMI Cardiac Action Potential Imaging System*



CONCARDIO MEDICAL INSTRUMENTS INC.

Post-Mortem for the Cardiac Action Potential Imaging System

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ABBREVIATIONS

BCRI or BCRICWH	BC Research Institute for Children's and Women's Health
CAPIS	Cardiac Action Potential Imaging System
CCD camera	charge-coupled device camera
CMI	Concardio Medical Instruments Inc.
DAQ card	data acquisition card
GUI	graphical user interface
IGM	image generation module
IAqM	image acquisition module
IAnM	image analysis module
IEEE	Institute of Electrical and Electronic Engineers
JET	junctional ectopic tachycardia
LED	light-emitting diode
POC	proof-of-concept
PMT	photomultiplier tube
QE	quantum efficiency
TTL	transistor-transistor logic



1 Introduction

In the past 13 weeks, Concardio Medical Instruments Inc. has been working on the proof-of-concept models of the Cardiac Action Potential Imaging System, CAPIS. Throughout this stage of development, the project focused on the design of a proof-of-concept model for our Cardiac Action Potential Imaging System (CAPIS). Much effort was directed in gaining the know-how and insight into the design and integration of such an imaging system. The results were successful. By first developing the proof-of-concept model, we have now equipped ourselves with more knowledge and experience in providing advancements in designing a functional prototype of the CAPIS, taking one step closer to providing a potentially powerful cardiac diseases research tool for our clients.

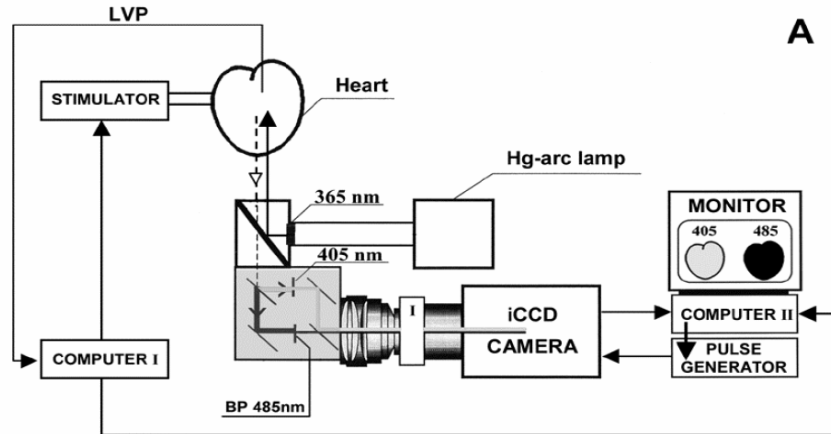
This document describes in detail the development outcome from proof-of-concept phase, any deviations from our original plans and previous documentations, and recommendations and future plans for our CAPIS system. Also included is a brief outline of our final budget and time constraints our team. Finally, each member of the team will explain and discuss the interpersonal and technical experience gained from participating in this endeavor.



2 Current State Of The System

2.1 Image Generation Module

The current design of this module can be described by the following diagram as shown below.



More specifically, a bath solution is prepared with live heart cells, extracted from rabbit hearts. These cells have been prepared with injecting di-8-amepps dye and Ca^{++} . The cell setup is detailed in the derivation from original function specification section. The cell is then simulated at 0.5Hz by a simulator. Healthy heart cells should then contract accordingly. For unhealthy heart cells, it would either contract independently to the simulator or contract irregularly with respect to the simulator.

The PMT is then setup to detect the photons released and refract them into the green wavelength and red wavelength via band pass filters (with 485nm) and mirrors. It is then sent to the Labview software module for researcher's analysis.

At this stage in the proof-of-concept model, due to time constraint, we are unable to observe concrete data. The reason being of the ten experiments that we conducted, six failed due to the unhealthy state of the rabbit. Of the rest of the experiments, only one healthy heart cell can be observed. Should we have conducted the experiment flawlessly, we should have observe the waveform as described in Figure 2-1 below:



Figure 2-1: Quasi-sinusoidal waveform with maximum frequency being 20Hz and minimum being -90Hz.



2.2 Image Acquisition Module

Before proceeding with this section, we wish to inform the reader that there are supplement documents provided separately. These supplement documents are written separately due to the vast amount of detailed information which we deemed not essential to this document, but necessary for the project and our client Dr. Glen Tibbits. The supplement documents for the IAqM include: GUI User and Development Manual, Functionality and Performance Analysis, and Camera Candidate Analysis and Recommendation.

There are two distinct components that make up the current proof-of-concept model IAqM: capturing an image using a CMOS camera; and displaying, manipulating, and saving images or videos captured via a graphical user interface (GUI).

The IAqM team used a Prosilica CV640 camera, which was provided by Dr. Glen Tibbits, to capture images for processing by our GUI created using LabVIEW. The Prosilica CV640 camera captures and displays black and white images. The camera connects to a computer through a IEEE 1394 FireWire port which transfers images from the camera to the computer and also supplies power from the computer to the CMOS camera. After images are transferred from the camera to the computer, the images are then processed by our LabVIEW GUI program.

We confirmed that the CMOS camera is working properly by installing the camera driver provided by Prosilica and linking the camera to the computer via a IEEE 1394 FireWire port. The camera's operation is verified using National Instruments' Measurement and Automation Explore, which provides controls to manipulate the camera settings. Continuous camera image output and other basic camera control features such as brightness, shutter, gamma, and gain are explored and verified to be functional via a run-through of the control options.

In the initial state of our GUI program upon start-up, there will be two windows displayed to the user, one window will display the continuous live feed of what the CCD camera is capturing and the other window is the control panel. The control panel provides the user with the ability to capture AVIs of the live feed, snap images of the live feed, load previously saved still images, save modified pseudo-colouring of loaded still images, and perform image manipulation on the live feed and previously saved still images. Frame rates can be set by the user for both the live feed and AVI capturing. The following Figure 2-2 is a screen shot of the GUI control panel window.

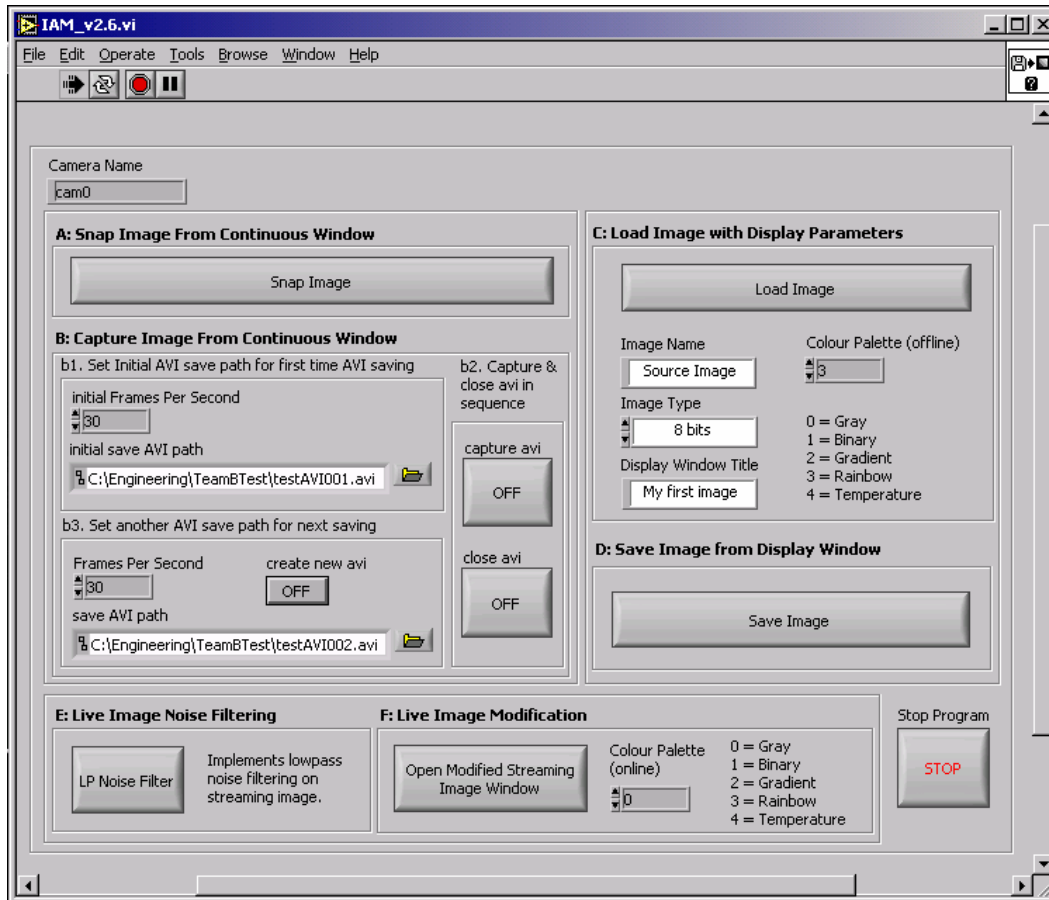


Figure 2-2: Screen Shot of GUI Control Panel.

The only image manipulation we have that can be preformed on the live feed is to perform pseudo-colouring. The user can chose to implement the rainbow colour palette on the live feed and the live feed will be coloured based on the light intensity level of the image. We can perform both the zoom function and pseudo-colouring on loaded still images. However, we can only save pseudo-colouring changes to the still image, not any zoom modifications. For further details regarding our GUI system, please refer to our “GUI User and Development Manual” document.

We were able to confirm that the GUI program was operating properly by capturing test images in typical room lighting on the CCD camera. From these captured images, we tested the capture, save, open, display, pseudo-colour, and digitally zoom functionalities to confirm their proper operation. In addition, under normal room lighting, 20 second videos are also captured and saved through the IAqM GUI to confirm the IAqM model’s ability to obtain videos of at least 20 second duration.

Various video frame rates are explored for the capturing and saving process. These test results suggest that the IAqM GUI is unable to properly save full resolution videos at Prosilica CV640’s maximum frame rate of 30fps operating under Windows OS. Note that Prosilica CV640’s full



resolution is approximately 640 by 480 pixels. In fact, it is believed that since the IAqM GUI is able to capture, but not save, at full camera resolution and frame rate, the problem is most likely due to the LabVIEW's image saving algorithm.

After the IAqM CCD camera and GUI have both been confirmed to be operating properly, we then proceed on with our performance experiments to find suitable frame rate, intensity, wavelength sensitivity, and resolution for our final system. The analysis and results of our proof-of-concept model is provided in the supplement document "Functionality and Performance Analysis".

2.3 Image Analysis Module

The Image Analysis Module's (IANM) main objective in the proof-of-concept model was to correct the distortion caused by motion artefacts, specifically the variations of the shape of the heart as we try to image a beating heart. We pursued two avenues of image matching to approach the problem, in the hopes that we could find the best solution. Detailed documentation was also prepared to accompany our code, as we appreciate that the extensibility of our work in the proof-of-concept phase is very important for the continued development of this project.

As specified in the functional specification, we generated polygon images with a greyscale gradient to test the two landmark matching algorithms. Recall that in order to determine static locations within the heart in an actual experiment, we proposed to use fluorescent landmarks (i.e. equipping the heart with quantum dots). We simulated these dots by scattering *salt noise* (white pixels with a random distribution) on the test images we created. The test images that were used are shown below in Figure 2-3 (without salt noise) and Figure 2-4 (with salt noise). We refer to these images as the *base image*.



Figure 2-3. Base test image.



Figure 2-4. Base test image with salt noise.

On top of the base images, we produced three different *input images*, each simulating different motion artifacts applied¹ to the base image. The position of the landmark dots are also shifted, as shown below.

¹ Note that a simple photo-editing program, such as Adobe Photoshop, can be used to perform such alterations. The terms *pinch*, *shear*, and *twirl* in Figure 2-5, Figure 2-6, and Figure 2-7 are terminology used in Adobe Photoshop.



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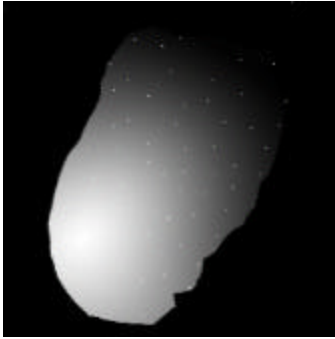


Figure 2-5. Input image 1: 20% pinch and horizontal shearing.

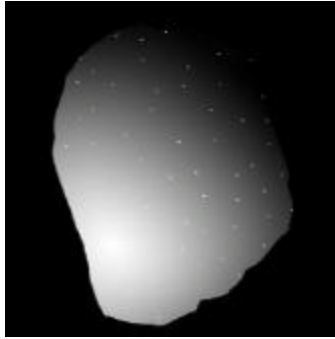


Figure 2-6. Input image 2: -20% pinch and horizontal shearing.

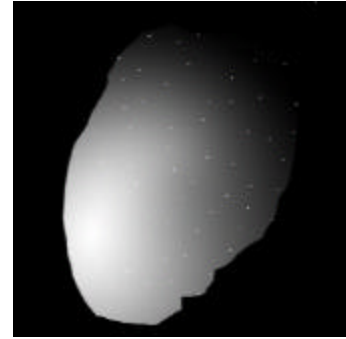


Figure 2-7. 50° twirl and horizontal shearing.

Matching of the landmarks was performing using a MATLAB tool called `cpselect` (short for Control Point Selection, which is MATLAB's terminology for landmarks). In this tool, the base and input images are shown simultaneously, allowing the user to locate corresponding landmarks on both images, as shown in Figure 2-8 below.

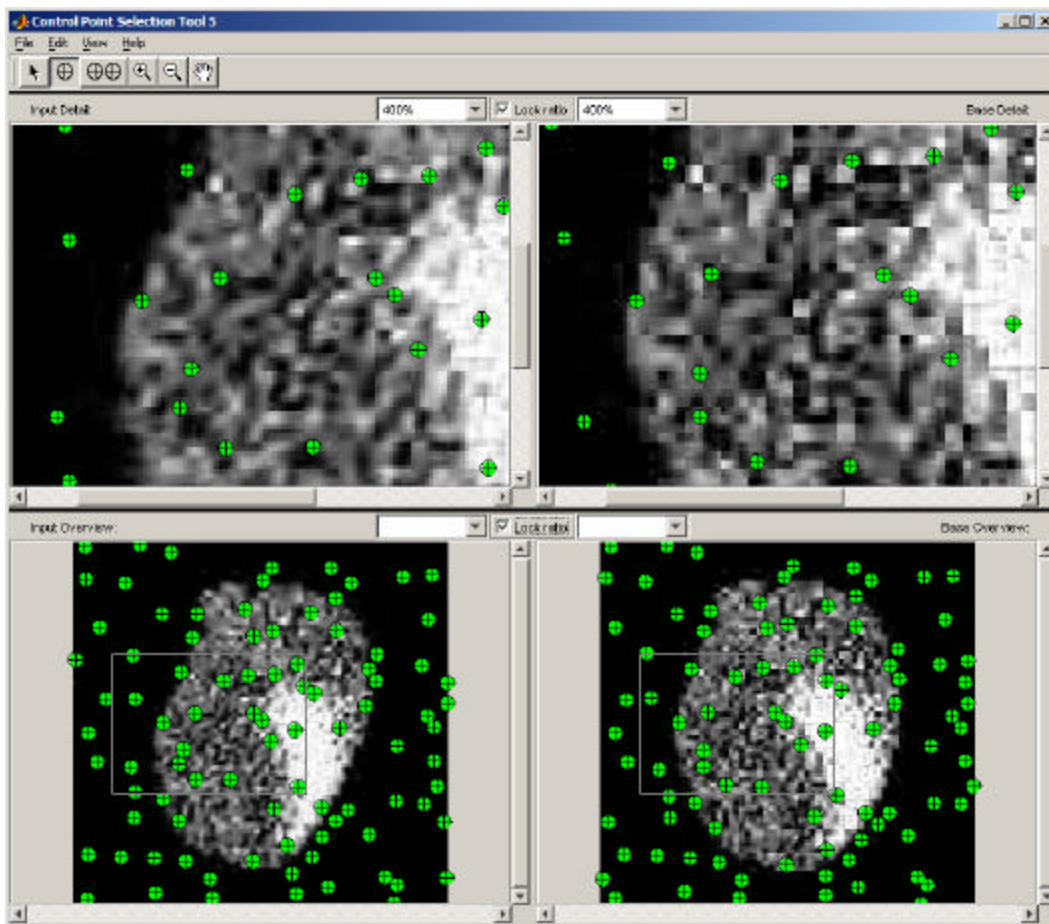


Figure 2-8. Using MATLAB's `cpselect` tool to correlate landmarks in two images.



We now briefly distinguish the two landmark matching methods used in our proof-of-concept model. These methods are:

- Local-weighted mean (LWM) transformation via MATLAB, and
- Geodesic interpolating splines transformation implemented by Dr. Faisal Beg

The LWM transformation is suitable for correcting distortions that vary locally. The geodesic interpolating splines approach, as described in a paper by Younes and Camion, uses an inexact matching algorithm based on increasing smoothness and minimizing a data-fitting term. Both of the algorithms, and the software implementation along with it, will be discussed in the next section.

2.3.1 MATLAB Local-weighted Mean (LWM) Landmark Matching

The image registration program developed in MATLAB uses the LWM transform method to match input images to the base image. Our previous documentations stated that the affine transform (used to distortion associated with rotation and shearing) was to be used. However, testing showed that the LWM transform was more suitable in dealing with the local distortions in the images.

As stated in our functional specifications, landmarks used in image registration need to be inputted by the user, which can be done through MATLAB's CPSelect Tool. Alternatively, the user can also input landmarks in the form of text files. To quantify the performance of the matching, the program generates an absolute difference image and computes a matching percentage, in addition to providing a visual comparison of the results. Finally, the software also provides the user with an iterative feature, in which the matching result from the previous run will be used as the input of the next run in hopes of improving performance should the user be unsatisfied with the results.

Performance of the MATLAB image registration software varies from approximately 75% to 95%. Matching is sensitive to the placement of the landmarks, in which performance is best when landmark distribution is even and decreases when the distribution grows uneven. The advantage of this algorithm, however, is its speed - the average execution time for one image is only 15 seconds.

For more detailed description of the algorithm and analysis of its results, please refer to the technical documentation provided to Dr. Tibbits.

2.3.2 Geodesic Splines Landmark Matching

As described, the geodesic splines landmark matching algorithm minimizes an energy term based on smoothness and a data-fitting (error) term. While the specifics of the algorithm are not



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discussed here (and will be found on provided software documentation), the software system designed to use this algorithm is outlined in the following block diagram.

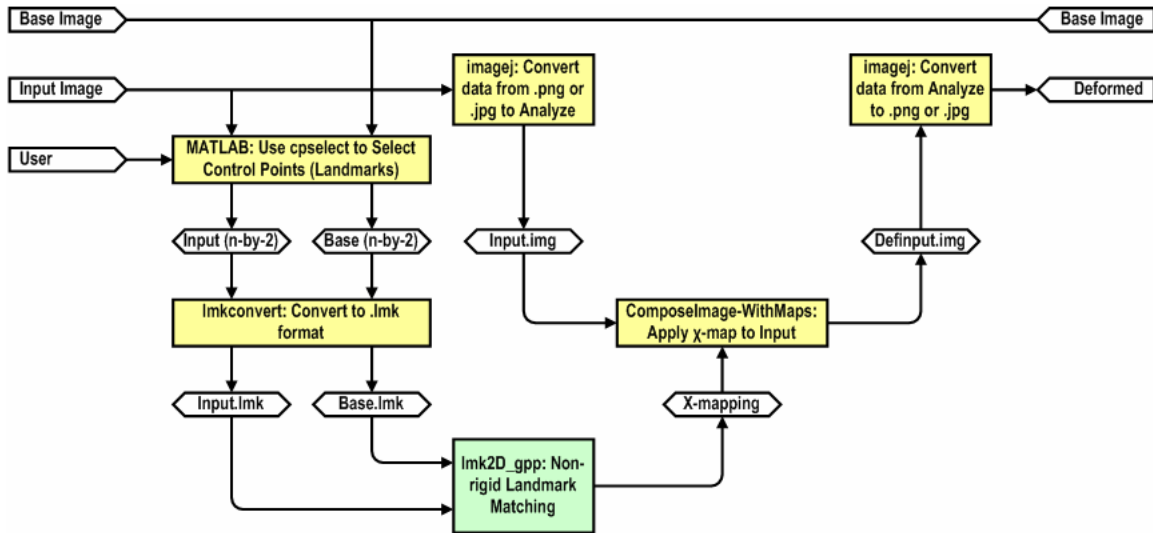


Figure 2-9: Block diagram of the geodesic splines image matching program.

From the block diagram, the user must first supply landmarks manually by using the `cpselect` tool (see Figure 2-8). After saving the landmarks to a text file, we use `lmkconvert` to convert the landmarks into a `.LMK` file, usable by the geodesic splines algorithm. Generating a mapping from input landmarks to base landmarks, we apply the map onto the image, converted to Analyze format from conventional image formats using ImageJ. Finally, using ImageJ to convert back to conventional image formats, obtaining the aligned (i.e. deformed) input image that matches the base image.

A more elaborate explanation of the system is described in the documentation for the Image Analysis team, available upon request.

2.3.3 Testing and Evaluation

Finally, we now discuss the tests for validity of the two approaches to landmark matching. Because no real test data was provided from other groups, we resorted to creating two sets of test data: the first set being the gradient polygons shown in Figure 2-3 through to Figure 2-7, and the second set being a set of sample rabbit heart data², illustrated in Figure 2-10 below.

² Provided by Vanderbilt University's <website www.vanderbilt.edu/lsp/panoramimg.htm>

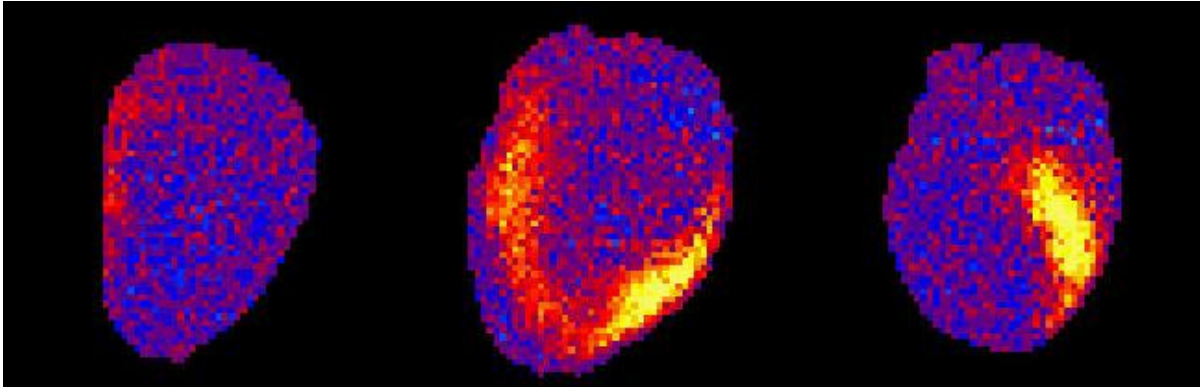


Figure 2-10: Realistic test data of fluorescent rabbit heart images.

As a qualitative measure of matching performance, we computed the absolute image difference between the base image and the output image from the each of the landmark matching systems. On a per pixel basis, if the image difference is great, then the pixel will appear bright; otherwise, the pixel will be black. For both algorithms for most of the matchings, we observed only a thin white ring around the edge of the test polygon, as shown below in Figure 2-11, clearly representing a good matching.



Figure 2-11: Example absolute difference image of a good matching.

We also justified the landmark matching results quantitatively. Totalling all intensities in the difference image (between the base image and the landmark-matched image), we used that as a percent matching error against the total intensity found in the base image. Using standard operating procedures, the two software systems provided the following matching results as described in Table 2-1.



Table 2-1: Matching percentage of the polygon data set (top) and the fluorescent heart image data set (bottom).

Geodesic Spline		Input01toBase	Input02toBase	Input03toBase
Polygons	All landmarks	98.480%	98.466%	97.614%
	Interior landmarks	96.904%	96.451%	96.961%
MATLAB		Input01toBase	Input02toBase	Input03toBase
Polygons	All landmarks	98.171%	74.314%	72.598%
	Interior landmarks	98.364%	74.314%	98.042%

Geodesic Splines				
Fluorescence Image	All landmarks	84.532%	Interior landmarks	83.857%
MATLAB				
Fluorescence Image	All landmarks	90.571%	Interior landmarks	77.137%

Both LWM and geodesic splines matchings performed remarkably similar in both test cases, generating about 97% for the testing polygons and about mid-80% for the sample rabbit heart data. We notice that the geodesic splines algorithm exhibited more consistency when compared to the LWM matching; however, we know for a fact that the geodesic splines algorithm requires a longer amount of time. The geodesic splines method requires an average execution time of 15 minutes per image, while the LWM method takes about 15 seconds to execute per image. After evaluating both algorithms, we believe that the LWM method can be developed as a quick tool to generate initial estimates, while the geodesic splines method can be used to deliver more accurate results, if the user can afford longer processing time.

3 Deviation From Original Functional Specification

3.1 Image Generation Module

The design of the model for this module followed closely to the functional specification except the method in preparing the sample bath specimen. The procedures on cell preparation is crucial to our experiment, hence we have made some adjustment as detailed below along with new setup procedures.

The result of the experiment is heavily dependent on performing correct cell extracting and testing procedures using the correct apparatus. First of all, a ten days old rabbit is dissected with caution so that the heart is removed in healthy condition. The cells are then extracted by enzymes from the heart. Cells are centrifuge and put in 1.5mM Tyrode solution, which contains NaCl,



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KCl and Ca^{++} and simulate blood solutions to maintain healthy cell environment. The samples are then put into a test tube and wrapped in tin-foil so that cells are not exposed to room lights. Extra Tyrode solution is readily available for later use.

The bath setup is needed to hold the cell for analysis under the microscope. The following apparatus, as shown in Figure 3-1, includes the microscope holder, the fascinator, the bath placeholder and the bath. They are cleaned with ethanol, water with kim wipe.

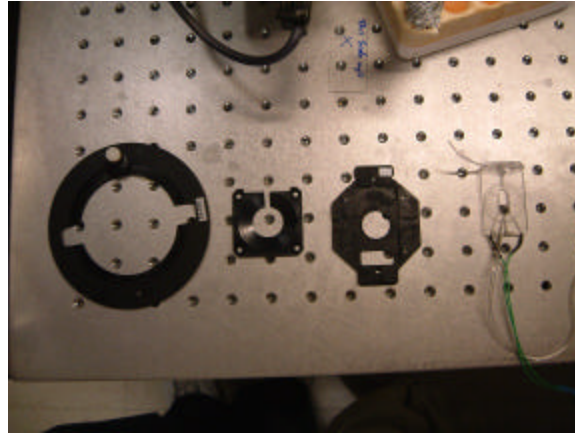


Figure 3-1: From Left to Right: Microscope Holder, Fascinator, Bath Placeholder, Bath.

Cells are then carefully pipette on the bath, between two plastic slides that used to seal both ends. Next, the bath is secured on the fascinator on the bath placeholder and then they are all put on the microscope holder, as in Figure 3-2.

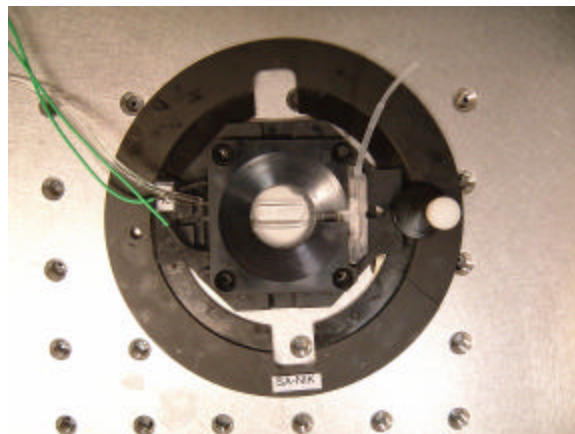


Figure 3-2: Final Setup of the Bath.

Next, the two green wires in Figure 3-3 is connected to the simulator with 0.5Hz. The width of the simulated pulse is 5ms, and the polarity is in biphasic mode. This is shown in Figure 3-4.



Figure 3-3: The Simulator with the Appropriate Setting

The mercury arc-lamp should be placed on the microscope. The lamp must also be focused.

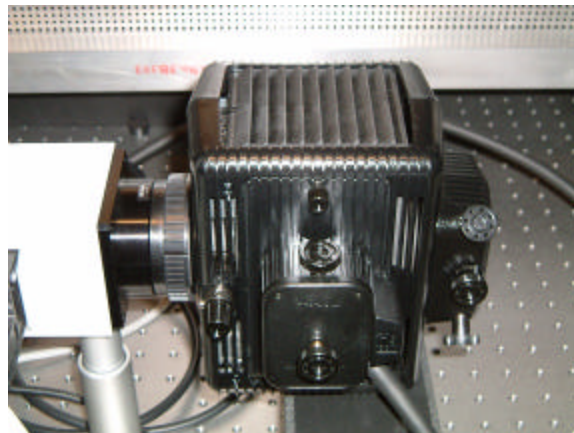


Figure 3-4: Mercury Arc-Lamp in Place on the Microscope

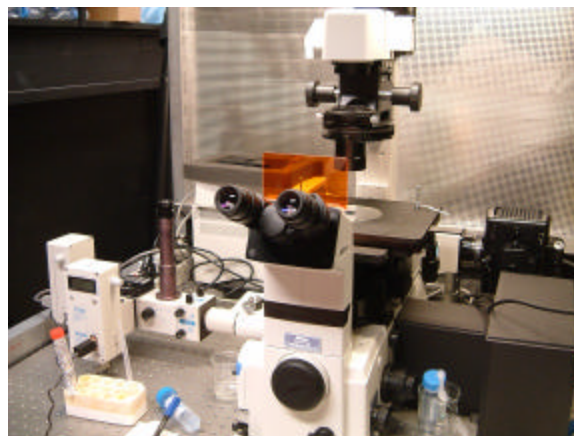


Figure 3-5: Microscope.



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Then, turn on the simulator and the microscope. The simulator generates a current between two platinum wires between the bath, hence simulating the cell. Looking into the microscope, contracting cells should be observed. Targeted cell should be elongated with striate. In addition, healthy cells contract 15% of their length on their two ends. Cells that contracts itself without the simulator or move in radial direction during simulation signals that they are unhealthy cells and should be disregarded. Since bubbles may form along the platinum wires, the bath should be constantly replenished so that current can be continuous conduct without the bubbles obstructing.

Afterwards, the PMT should be placed on the left side of the microscope for the capturing of the wavelength. The two PMT are placed perpendicular to each other, as shown in Figure 3-6, to capture the two wavelengths.

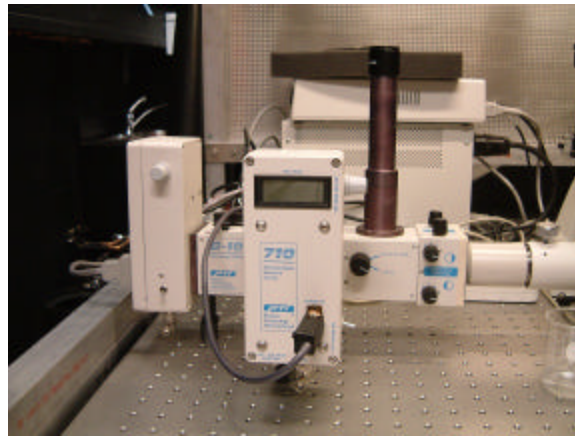


Figure 3-6: PTI 710 PMT

Coaxial cable is connected between the PMT and the connector block, as shown in Figure 3-7.

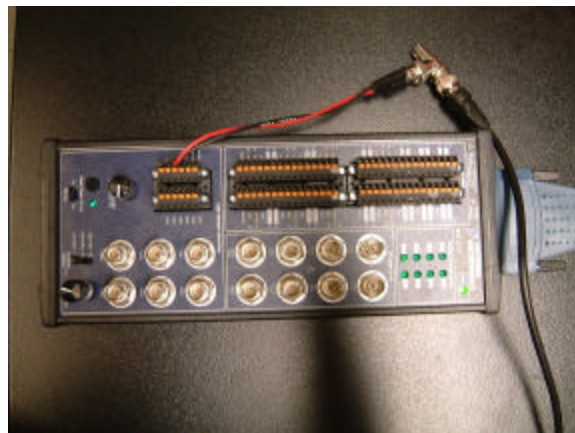


Figure 3-7: National Instruments BNC-2121 Connector Block



The connector block is connected to the PCI-6602 card with the computer. LabVIEW will then interpret the results and show on the results on the screen. Afterwards, the mercury arc-lamp is turned on. We have to ensure that the image is focus and isolated from the other cell. Since the cell's membrane is the component that fluorescence, we have to include all the membrane in the isolated image. Any extra cell over lapping or appear during the capture is considered to be a disturbance and will decrease the signal-to-noise ratio hence lower our performance to achieve a good result.

3.2 Image Acquisition Module

Overall in the IAqM, all the features, test plans, and experiments went as outlined in our project proposal and functional specifications. However, there were some deviations from the original outline as we progressed through the project.

3.2.1 Opening Saved AVIs

We discovered that we were not able to open AVIs, one of our image display functionalities, because of the version of LabView are working on does not support this feature. We were initially lead to believe this was possible because when we did the research on the LabVIEW product, we go the version numbers confused. We are working on LabVIEW 6.0 and the version of LabVIEW that can open an AVI is in LabVIEW 7.0. We could not upgrade to LabView 7.0 to gain the ability to open AVIs because the IMAQ add on we had was for LabView 6.0 and would not work on LabVIEW 7.0. Since we can not open AVIs, that also means we were not able to modify saved AVIs. The modifications to the AVIs we had outlined were pseudo-colouring and zoom function on the saved AVIs.

3.2.2 Pseudo-Colouring Live Feed

After we discovered that we were not able to open saved AVIs, we decided to the option of pseudo-colouring to the live video feed. In our current program, one can click a button to have the live feed pseudo-coloured.

3.2.3 Saving Zoom Modified Images

In our current system, one could open a still image and perform zoom operations on it. However we have not found a way to save the modified still images with the modified zoom. We discovered this near the end of the project and we did not have enough time to further investigate this problem. However we strongly believe that this functionality is possible to implement.

3.2.4 Noise Removal

In our functional specifications we stated in our general requirements that we would have a noise reduction mechanism in place if the noise introduced by the capturing and transmission hardware was more than 25% noise-to-signal ratio. However we found it very difficult to quantify the



noise-to-signal ratio when we had the final live feed of the image. We limited the meaning of noise to periodic and/or salt-and-pepper noise that are visually apparent. We were not able to observe any of these noises and decided to implement a noise reduction mechanism to compare any improvements from the noise reduced images. We were not able to observe any differences in the images with the noise reduction mechanism in place. However we did left the option to the user to turn on or off the noise reduction mechanism anytime in the program.

3.2.5 Proof-of-Concept Experiments

We outlined very briefly in our functional specification how we were going to conduct the POC experiments to find the necessary for frame rate, intensity, wavelength, and resolution for our final system. The POC experiments are designed to benchmark the model's performance in addition to its basic capturing capabilities. The results were analyzed and partially quantified to provide a better understanding of the model's performance achievements. The following is an outline of each experiment's procedure.

3.2.5.1 Frame Rate

A metronome with a blinking LED is used to emulate the optical emission conditions of a rabbit heart subject such that the typical contraction rate of study interest is quasi-simulated. More specifically, the blinking LED simulating the contraction rate is used to test if the IAqM GUI is capable of capturing the information from the optical emission of a rabbit heart subject without losing any data.

3.2.5.2 Intensity

Still images are captured at low intensity lighting, simulating a low light-intensity image source through the IGM's optical pathway, is captured using various camera shutter speed, gain, and brightness settings. The intensity response of a still image is assumed to be the same for streaming video captures. Images of rabbit heart cell specimens are used as subjects. The camera is connected directly to a microscope at an overall 10x magnification and low intensity top projection halogen lamp at ½ - 6V30W setting.

3.2.5.3 Wavelength

An image is captured composing a spectrum with wavelengths ranging 400nm to 700nm is derived from a mercury arc lamp light beam projected through an optical prism. Although the white light is not made into a coherent parallel beam prior to projecting through the optical prism, the resulting light spectrum is sufficient in providing preliminary performance benchmarking of the IAqM GUI's ability to capture images composed of wavelengths ranging from 300nm to 800nm.

3.2.5.4 Resolution

Resolution analysis was performed by capturing images of the rabbit's cardiac cells which were projected through the same microscope used as the IGM's optical pathway.



3.3 Image Analysis Module

All high-priority requirements laid out by the IAnM team were completed successfully. The only low-priority requirement pertains to the development of a graphical user interface (GUI). We did not develop a GUI to encapsulate the LWM and geodesic splines programs, and instead opted to use a more simple command line interface. We decided not to develop a GUI at this stage for two reasons. First, the focus at this proof-of-concept phase is to evaluate the performance of the algorithms. The programs serve as a developer's tools, so they do not warrant a commercial-release grade GUI. Second, the time originally allotted for user interface development was near the end of the project, when we would decide whether to wrap the programs with a GUI depending on the progress of the Image Analysis team and also the progress of other modules. Since at the time there was a need for more manpower in the other modules to accomplish their objectives, we decided not to implement a GUI because it was a lower priority task.

4 Budget

Table 4-1 below shows an estimate cost for the project during this proof-of-concept phase provided during the beginning of this phase.

Table 4-1: Budget estimate for CAPIS proof-of-concept model development phase. (All dollar figures listed are in Canadian currency)

Module	Component Description	Cost
Image Generation	Biochemically Stimulated Arrhythmic Rabbit Heart [*]	Provided by BCRI
	Potentiometric Dye Solution	Provided by BCRI
	Optical Pathway Mechanical Enclosure and Base	\$500
	Optical Components (lenses, mirrors [*], filters)	\$500
Image Acquisition	Experimental Digital CCD Camera HW and SW [*]	Provided by BCRI
	CCD Camera Zoom Lens	\$500
	Desktop Computer Unit (PC)	Provided by BCRI
	Realtime Imaging Output Software	To be developed
Image Processing	Offline Image Processing Software	To be developed
Administrative	Company Registration	\$450
Contingency	Includes but not limited to possible camera trial/exchange fees, shipping fees, optical/mechanical setup fabrication cost overruns (20% of total)	\$390
	Total	\$2,340

* Existing components provided by Dr. Tibbits and lab associates.



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Although the initial estimate suggests a relatively large amount of \$2340, the actual cost incurred can be summarized as follows: research and development equipment costs of \$362.65; company registration and administration cost of \$512.05. The total is approximately \$872.40, more than one-thousand dollars shy of the initial estimate. This is largely due to the change in design for the model Image Generation Module, along with overestimation on the camera zoom lens.

Table 4-2 summaries the costs of equipment acquired. Notice that the additional equipment purchase is accounted for under the initial contingency cost estimation.

Table 4-2: Actual acquired equipment costs during proof-of-concept phase.

Module	Component Description	Cost
Image Generation	Heat sink and accessories	\$18.82
	Lexon blue LED and power supply	\$68.11
Image Acquisition	USB Firewire cable	\$41.81
	Lens for camera (Bock Optronics)	\$186.61
Total (after tax)		\$362.65

5 Time Constraint

5.1 Image Generation Module

Figure 5-1 below is a Gantt chart of the initial IGM project timeline.

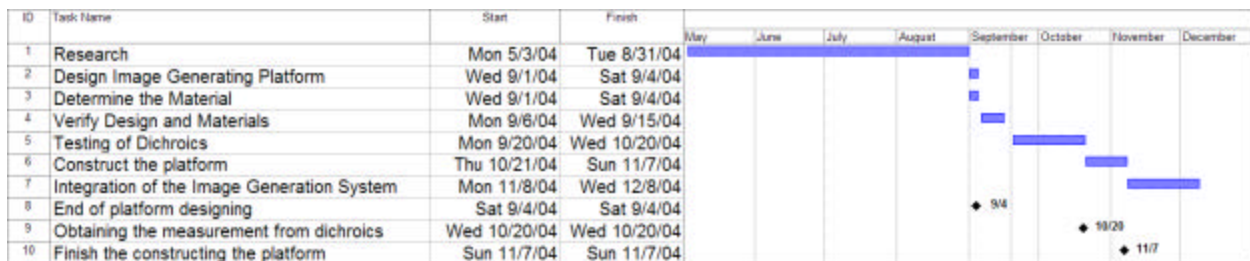


Figure 5-1 Gantt Chart of Initial IGM Project Timeline

Due to purchase order administrative complications, equipments arrival time was delayed and hence the module development progress obstructed. While waiting for critical optical components to arrive, much effort and time was spent on further development of the design and on revolving the complications. Unfortunately, due to the complication described, most of the testing and verification was unable to begin until late December, leaving insufficient time to gather solid results as discussed in the Current State of System – Image Generation Module section previously.



5.2 Image Acquisition Module

Figure 5-2 below is a Gantt chart of the initial IAqM project timeline.

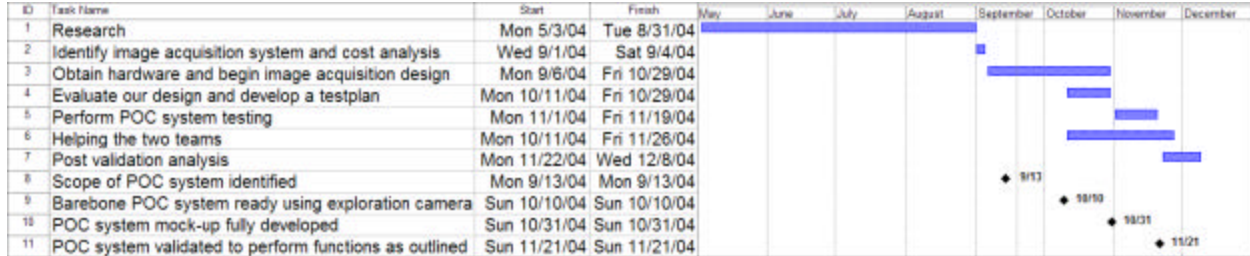


Figure 5-2: Gantt Chart of Initial IAqM Project Timeline

From Figure 5-2 above, task IDs 9, 10, and 11 actual completion dates were delayed by approximately two weeks each because obtaining the CCD camera and the test computer took longer than expected. Due to these delays, we did not have the time to assist the other two teams, task ID 5 from Figure 5-2. However, the other task progressed and completed as planned and each task, with the exception of task ID 5, maintained the same duration.

5.3 Image Analysis Module

Figure 5-3 below is a Gantt chart of the initial IAnM project timeline.

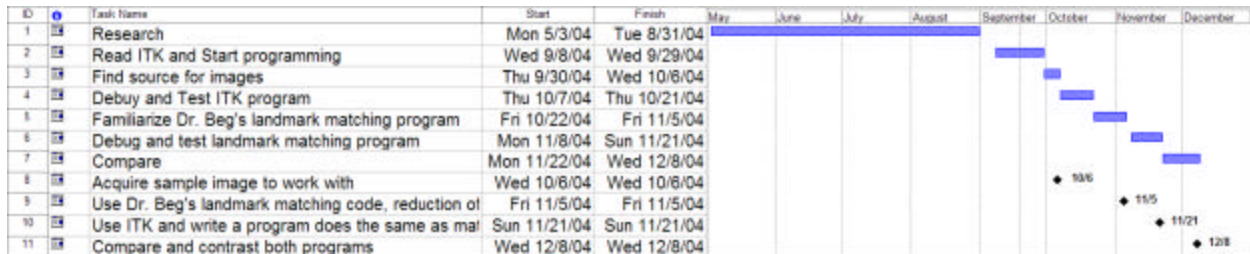


Figure 5-3: Gantt Chart of Initial IAnM Project Timeline

Several deviations from our original time budget occurred during the semester. The major change is the decision to use MATLAB instead of ITK. When this budget was originally conceived, the two member of the Image Analysis team had planned to write two branches of the program. But due to the difficulty in coordinating a common schedules, we decided to pursue a parallel course, in which one member will be responsible for the geodesic splines algorithm, and the other member will be responsible for the MATLAB portion of the module. Hence, development of the module code was done in parallel rather than in the sequential manner outlined in the original budget. However, the time spent on development roughly correspond with the budget, and the testing was completed by the testing deadline as per the budget.



6 Recommendations and Future Plans

6.1 Image Generation Module

For the Image Generation Module, it is strongly advised that the more experiments to be made in the following areas:

1. Experiments should be conducted without the dye. Since majority of the rabbit heart cells are not able to contract, we suspect that the dye might have played a role in the problem.
2. Next group following the project should get practice on preparing the cell. If that is the case, the experiment would have been smoother.
3. Instead of dissecting live rabbits, cell lines can be used. The advantage of cell lines is that it can be grown by itself without dissecting numerous rabbits for our purposes. Moreover, these cells can last a lot longer than regular rabbit live cells, which can only be last for approximately five hours.
4. In terms of software development, the labview module can be further improved such on the ability to count significant digits.

6.2 Image Acquisition Module

Before proceeding with this section, again, we wish to inform the reader that there are supplement documents provided separately.

The concept of devising the IAqM with a digital camera controlled and outputted through a graphical user interface as described in the IAqM model design seems to be a sufficient approach to the design of this module for the next, functional prototype, phase of the CAPIS system. The high-level design of this module will thus remain the same; however, reselection of the module's camera candidate may be necessary in addition to modifications and refinements to the capturing and output displaying software.

A camera as described in the "Camera Candidate Analysis and Recommendation" documentation can be adopted for the development of the IAqM in the functional prototype phase. This camera must provide frame rate adequate to capture the electrical signal propagation activity of the heart specimen; resolution and pixel size adequate to capture a clear view of the entire heart specimen such that the electrical propagation activity may be studied for its characteristics; imaging area adequate to receive all optical information translated from the IGM, and hence support the output dimensions of the IGM; quantum efficiency adequate within the 300nm to 800nm range to accommodate potentiometric dyes such as the Di-4ANEPPS emitting in this range.

Software modifications are also necessary. One of these modifications corresponds to the possible difference in driver-to-software compatibility between the new candidate camera driver and the current. This must be addressed if the new candidate camera requires a different set of interfacing hardware and drivers. Other modifications include desired improvements in the



processing speed performance, functionalities, and error handling mechanisms of the capturing and display GUI software. The specifics of these later desired modifications are discussed in further detail under the “GUI User and Development Manual” documentation.

The development of the functional prototype following the current completion of the proof-of-concept model thus requires a fair amount of considerations and modifications in terms of camera selection and software compatibility.

6.3 Image Analysis Module

As we mentioned in Section 2.3.3, we believe that both the LWM transform method and the geodesic splines method deserves further development. However, there are some recommendations that could improve their performances.

For the LWM algorithm, the current image I/O scheme requires the user to specify input and output locations one image at a time. When the number of images is large, which is quite probably the case with actual input images captured over a time period, the current I/O system will be cumbersome. One possible remedy to this problem is to give the user an option to execute the program in batch mode, in which all the input and output image locations are given prior to execution. Batch mode execution should make the program more convenient with large data sets.

In the geodesic splines front, we could improve efficiency of the program by optimizing the parameters used in the algorithm. For example, currently the geodesic splines algorithm executes 1000 iterations, but the energy actually converges a lot sooner than that (stabilizing energy means the matching is complete). Hopefully, altering the value of some of the parameters may decrease the long execution time of the algorithm.

Finally, we plan to automate or semi-automate the landmark selection process. Currently, we require the user to manually select landmark for each image, which becomes impractical when the number of images is large. An alternative is to have the user manually select the landmarks for the base image. Then, assuming the camera has a high enough frame rate, the movement of landmarks from image to image should not be too great. As a result, given the coordinate of a landmark in the base image, we can apply a cross-correlation using a kernel centered at the same coordinates in the input image. The pixel that yields the highest value in the correlation result will be the likely place where the landmark in the input image would be. Using this method, we can have a mapping between adjacent image, and can theoretically transform all images back to the base.



7 Interpersonal and Technical Experience

7.1 *Ronnie Chan*

This project was great learning experience, but it was also a source of frustration at times. Because we had initially underestimated the scale of the project, we had to cancel our original plans to build a prototype and scale down the project to a proof-of-concept nature. This change of plans challenged our adaptability as a group, but also served as a valuable lesson as project schedules often have to be modified to suit the dynamics of the work place.

Communication between group members was difficult at times because of the large size and the busy course load of our group. It was particularly challenging to play a leadership role in this group, but the lessons I learned in group dynamics and team management was well-worth the effort. I also have the chance to participate in a lot of external relations, having the chance to interact with Dr. Tibbits and the staff at BCRI. The experience to handle professional relations I believe will serve me well in my career.

This project was a particularly rewarding experience for me in the technical front, as it coincides with my interest in image processing and biomedical engineering. I learned how to develop image processing applications in MATLAB. In addition, this project also exposed me first-hand to biomedical applications of engineering in the field. I believe the experience I gained through this project will help me greatly in my effort to build a career path in image processing and biomedical engineering after graduation.

7.2 *Yindar Chuo*

The process of this project course contributed to the diversity of my undergraduate education. Each aspect of the project provided its own unique and valuable experience both in expanding my technical knowledge and in strengthening my interpersonal fluency. This project being developed under three separate modules and managed internally by administrative and business development teams allowed project members to gain direct experience in many sectors of a business and project development process.

One of the particularly notable business development experiences was the opportunity to discuss various corporate financing strategies with representatives from the University Industry Liaison Office introduced by Mike Volker. Additional valuable knowledge regarding financing options and initial network was established through the meeting. This opportunity also provided the company and its representatives exposure in consultation meeting approaches.

Although the technology development exposure was limited to a very researched based venue, it provided me a basic introduction to the dynamics of technology development. Among the technical knowledge I gained, understanding of the operations of developing simple LabVIEW based software, understanding of basic industrial research grade digital camera technologies, and understanding of the fundamental concepts on imaging with biological dyes were the most profound.



The technology development knowledge, business dynamics, small corporation operations, and interpersonal and social fluidity experience gained through the process of this project course is thus truly beneficial in furthering my personal education.

7.3 Jimmy Tsui

The experience I have gained from working on this project is invaluable. I have learned a lot on the technical aspects and also grown personally as a person. I felt part of a team, contributing and gaining experience working on the CCD camera and LabVIEW program. One can not simulate the real life problems encountered when working on a project like this in any classroom setting. This was a very tough project, however, after everything has been said and done, I felt that the hard work and effort was well worth it.

On the technical side, I was able to work very closely with the CCD camera and the LabVIEW program. I have learned a lot about the specifications of a CCD camera and their interface with the computer. I have never worked with LabVIEW before and found that the learning curve was very steep. After getting helpful and friendly technical assistance from NI, we were able to quickly understand all the necessary programming icons for our needs within LabVIEW. From the experience of trying to learn LabVIEW, I found that I could spend hours upon hours trying to figure out what each programming icon does but I can save lots of time by just asking someone with experience with LabVIEW. In a time constraint project like this, effective use of time is crucial and every second saved is a second we can use on something else in the project.

There were times in during the project when I did not feel the motivation to work on this project. Where the course load of other classes were piling on and the priority to work on this project was fairly low. Thankfully this was a group project and I had my other group members to motivate me through those tough times. We also realized that we all had other courses to work on and that we can cover each other, we do not need everyone to be working on the project at the same time. For a long term projects like this one, I found that without fellow group members to help and motivate each other we would not be where we are today.

I have gained tremendous team-working, research, and communication skills and experience from this project. I would like to thank Seddrak Luu and Dr. Glen Tibbits for the opportunity to work on this project. As they say, nothing good comes easy.

7.4 Edwin Wong

The past 8 months have been a frustrating yet rewarding experience for me. I learned much about project management, such as task scheduling, planning, and team organization. Project management proved to be one of the most important aspects when interfacing with the industry. When attending university, professors will make life easier for the students by planning the work deadlines and providing all necessary equipments, or at least the students hope so. However, being part of the management team for a project interfacing with the industry, all the planning



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and scheduling (and thus the success of the project) lies in our hands. I learned that it is important to have a detailed plan of the parts needed to not only get a head start on the development and operating other tasks while waiting for the parts to arrive, but also to give us some flexibility in time if and problems do arise during delivery of the parts.

Communication between subgroups or departments of the project team is important as well. Although overflowing email inbox and expensive phone bills may be annoying, I think it's worth it.

As for the technical side, I was responsible for the Image Acquisition Team where we developed a system to capture images and videos through a CMOS camera and a GUI control. Some obvious things I learned was application development using National Instruments' LabVIEW, becoming familiar CMOS and CCD camera functionalities and qualities, and data acquisition experience. Also, I helped the Image Generation Team a bit in stimulating and imaging rabbit cardiac cells, which gave me the feeling that the biological system side of the project is equally as interesting. Lastly, through the last 8 months, from researching and problem solving to developing and debugging, I learned that not only does one have to be creative to solve a problem, but also be persistent and eager in trying to overcome a challenge.

7.5 Stephen Wong

In late 2003, when I joined the team that eventually became Concardio Medical Instruments Inc., I knew that this project was a defining one in my undergraduate career—and indeed it has. I was fortunate enough to work alongside the brightest students in the academic faculty, and the experience gained from the required communication, research, and business practices are incomparable to any other academic course. Despite setbacks due to unforeseen administrative situations, we were still able to develop CAPIS to complete the proof-of-concept stage of the development cycle.

I quickly realized that despite being good friends with most of the team members before the project, everyone has different methods, approaches, and opinions about aspects the project. Luckily, our team members were fast to cope with differences and proceeded to work on the common goal. I also realized that this project was one that time pressure was immense and extremely crucial in successful completion of the project. Time management was eased through the early development of time schedules. Also, regular team meetings were encouraged and I was surprised that, despite just providing progress updates to the different teams, the meetings kept the group together during low times of the project, especially during administration problems halfway during the fall term.

The technical experience I gained was invaluable. I continued to strengthen my computer programming techniques by working with Ronnie on the Image Analysis team, and also gained product researching skills with Yindar in the dye selection committee earlier in the project. Because the project was research-oriented, it opened up a new aisle for study, should I continue



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studying after obtaining an undergraduate degree. I was also able to work with the other modules and provided insight to some of their problems when necessary.

I would like to thank the president, Seddrak Luu, and CEO, Ronnie Chan, for their endless leadership in Concardio Medical Instruments, and the rest of the team members for their continued support for the project. I would also like to thank our project associates, Dr. Beg, Dr. Tibbits, and Dr. Rawicz for their interest in Concardio's project.



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